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Sustainable management of industrial wastes in concrete industry

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Abstract

The use of industrial waste in concrete manufacture gives an appropriate solution to many environment concerns and burdens associated with waste management. A large amount of industrial waste such as Bagasse ash, Coal bottom ash, Blast furnace slag, Copper slag, etc is produced in most of developing as well as developed countries. In the last few decades there has been speedily increase in these waste. This obviously causes for many environmental issues and raises the potential to contaminate natural resources of living such as water, air and soil. So, the appropriate disposal of these wastes and by products is a serious burden of every country. The safe disposal of such industrial wastes is very expensive. Furthermore, there is a lack of disposal sites which can appropriately handle such wastes without causing harmful effects on the environment. Fortunately, the use of industrial waste in concrete is a suitable path towards effective disposal of waste as well as preservation of natural resources of aggregates. Several researchers have investigated the possible use of these wastes as cement and aggregates in concrete and its effects on the different mechanical and long term properties of mortar and concrete. The use of these wastes in cement and concrete provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of these wastes is produced.

Keywords: Concrete; Industrial waste; Bagasse ash; Coal bottom ash; Hypo sludge

1. Introduction

1.1 Issue related to present concrete industry

Concrete is a material synonymous with strength and longevity. Next to water, it is the second most used substance on earth. Due to its mechanical and durability properties, it has become an indispensable part in construction works. Unfortunately, the present construction industry is cursed with aggregates and cement related problem. The cement production has a large contribution in CO_2 emission because during cement manufacturing limestone and shale are heated in a kiln to higher temperature and grinded the resulting clinker with gypsum. One ton of cement is released an equal amount of carbon-dioxide into the atmosphere. Cement industry is responsible for about of 5% of global anthropogenic CO_2 emissions (Worrell et al 2001). Sometimes before, the aggregates were easily available but at present the concrete is cursed with scarcity of aggregates. The negative impact of increasing demand for concrete is leading to extensive extraction of aggregates from natural resources. This excessive extraction results into environmental degradation, ecological imbalance and create a question about the preservation of natural resources of aggregates. So, it has challenge to every engineer and researcher to search alternative which can replace the cement and aggregates.

1.2 Waste production: A serious burden

for industry

There is another big problem with which almost each and every country is suffering. In the last few decades there has been speedily increase in the waste and by-products production from the various industries. This obviously causes for many environmental issues and raises the potential to contaminate natural resources of living such as water, air and soil. So, the appropriate disposal of these wastes and by products is a serious burden of every country. The safe disposal of such industrial wastes is very expensive. Furthermore, there is a lack of disposal sites which can appropriately handle such wastes without causing harmful effects on the environment.Many of industrial waste such as Coal bottom ash, Blast furnace slag, Copper slag, etc. cause a waste disposal crisis, thereby leading to the environmental problems. The coal fired thermal power plants burn about 407 million tons of coal for generation of power and produce about 131 million tons of coal ash annually(Singh and Siddique 2014). On the other hand, to produce every ton of copper, approximately 2.2-3 tons copper slag is generated and approximately 24.6 million tons of slag is generated from the world copper industry (Gorai *et al* 2003). In India three copper producers- Sterlite Copper, Birla Copper and Hindustan Copper produce approximately 6-6.5 million tons of copper slag annually at different sites (Narasimhan 2011). This waste production can be reduced by making more appropriate use of the industrial waste.

1.3 Concrete industry: A suitable place for waste utilization

The use of industrial waste in concrete is a suitable path towards effective disposal of waste as well as preservation of natural resources of aggregates. Several researchers have investigated the possible use of these wastes as cement and aggregates in concrete and its effects on the different mechanical and long term properties of mortar and concrete. The use of these wastes in cement and concrete provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of these wastes is produced.

2. Sugarcane bagasse ash (SCBA)

Sugarcane bagasse ash is waste from sugar industry. As we know that, sugarcane is one of the major crops grown in over 110 countries. The fibrous matter that remains after crushing and juice extraction of sugarcane is known as bagasse. Nowadays, this bagasse is to reutilize as a biomass fuel in boilers for vapor and power generation in sugar mills. When this bagasse is burned under controlled temperature, it results into ash.

2.1 Properties of SCBA

The SCBA consists of mainly oxide of silicon, iron and aluminum which make it pozzolanic material by satisfying the chemically requirement of a good pozzolan as specified by BIS code. The chemical composition and physical properties of SCBA is given in Table 1.

Table1: Chemical composition of SCBA

Chemical composition	Cordeiro et al. (2008)	Janjaturaphan and Wansom (2010)	Ganesan et al. (2007)
SiO_2	78.34	75.27	64.15
Al_2O_3	8.55	5.38	9.05
Fe_2O_3	3.61	2.54	5.52
MgO	-	1.15	2.85
CaO	2.15	3.74	8.14
LOI	0.42	7.18	4.90

2.2 Workability and strength characteristics of SCBA concrete

Chusilp et al (2009) investigated the physical properties of SCBA concrete such as compressive strength, water permeability, and heat evolution of SCBA. They replaced cement with SCBA at different replacement levels (10, 20 and 30%) with constant w/c ratio (0.50). They concluded that, at the age of 28 days, the concrete samples containing 10–30% SCBA by weight of binder had greater compressive strengths than the control concrete. Concrete containing 20% SCBA had the highest compressive strength at 113% of the control concrete. The effect of different curing ages and percentage replacement of SCBA on compressive strength is illustrated Figure 6. They were also used super plasticizer to control the slump of fresh concrete. According to them, SCBA can be used as a pozzolanic material in concrete with an acceptable strength, lower heat evolution, and reduced water permeability with respect to the control concrete. Cordeiro et al (2010) described the characterization of SCBA produced by controlled burning and ultrafine grinding. Initially, they were examined optimum burning conditions of the bagasse which helped them to find maximum pozzolanic activity. The results demonstrated that an amorphous SCBA with high specific surface area and reduced loss on ignition can be produced with burning at 600 °C in muffle oven. After observing optimum burning they investigated the grinding procedure of SCBA. They concluded that the grinding in vibratory mill for 120 min enabled the production of an ash with pozzolanic activity index of 100% which can be replaced cement up to 20%.

Fairbairn et al (2010) studied the effect of SCBA as partial replacement of cement in concrete. SCBA was replaced with cement at the ratio of 0%, 10%, 15% and 20 %. All specimens were cured for 7, 28, 90 and 180 days. Based on their test results, they concluded that an optimum of 10% SCBA blend with OPC could be used for reinforced concrete. Ganesan et al (2007) studied the effect of SCBA as supplementary cementitious material on the properties of concrete. Seven different proportions of concrete mixes (bagasse ash ranging from 5% to 30% by weight of cement) including the control mix were prepared with a water binder ratio of 0.53. Compressive strength of bagasse ash blended cement concrete cubes was determined after 7, 14, 28 and 90 days curing. This study concluded that up to 20% of cement can be replaced with SCBA without any adverse effect on the strength of concrete while 10% of cement can be replaced to achieve desirable workability of fresh concrete. Lavanya et al (2012) studied the effect of SCBA as partial replacement of cement in concrete. SCBA was partially replaced with cement at the ratio of 0%, 5%, 10%, 15% and 30% for three different water cement ratios i.e. 0.35, 0.40 and 0.45. For each water cement ratio and replacements 3 cubes were casted and its average compressive strength is tabulated for 7, 14 and 28 days. According to the results obtained, it can be concluded that: SCBA can increase the overall strength of the concrete when used up to a 15% cement replacement level with w/c ratio of 0.35. Otuoze et al (2012) investigated the effect of sugarcane SCBA as partial replacement of cement in concrete. All cube specimens were cured for 7, 14, 21, and 28 days for 0, 5, 10, 15, 20, 25, 30, 35 and 40% SCBA blended with OPC. The compressive strength of the specimens was determined in accordance to BS 1881 (1983). Based on the various tests conducted, it can be succinctly concluded that SCBA is a good pozzolana for concrete cementation and partial blends of it with cement could give good strength development and other engineering properties in concrete. An optimum of 10% SCBA blend with cement could be used for reinforced concrete. Higher blends of 15% and up to 35% of SCBA with cement are acceptable for plane or mass concrete. Rukzon and Chindaprasirt (2012) studied the effect of SCBA as partial replacement of cement in high strength concrete. In this study cement was partially replaced with 10%, 20% and 30% of SCBA. For all mixes, 100 mm diameters and 200 mm height of cylindrical specimens were cast for compressive strength testing. They were tested at the ages of 7, 28 and 90 days. This study concluded that coal SCBA improves the strength of concrete. The concrete containing up to 30% of SCBA exhibited better compressive strength than conventional concrete. Srinivasan and Sathiya (2010) studied the effect of SCBA as partial replacement of cement in concrete. SCBA was partial replaced with cement at the ratio of 0%, 5%, 10%, 15% and 25% by weight. This study examined the workability, compressive strength, split tensile strength, flexural strength, young's modulus and density of concrete. The results explained that the SCBA in blended concrete had significantly higher workability, compressive strength, tensile strength, and flexural strength compare to that of the concrete without SCBA. It is found that the cement could be advantageously replaced with SCBA up to maximum limit of 10%. The compressive strength result are shown in Figure 7.

Chusilp et al (2009)

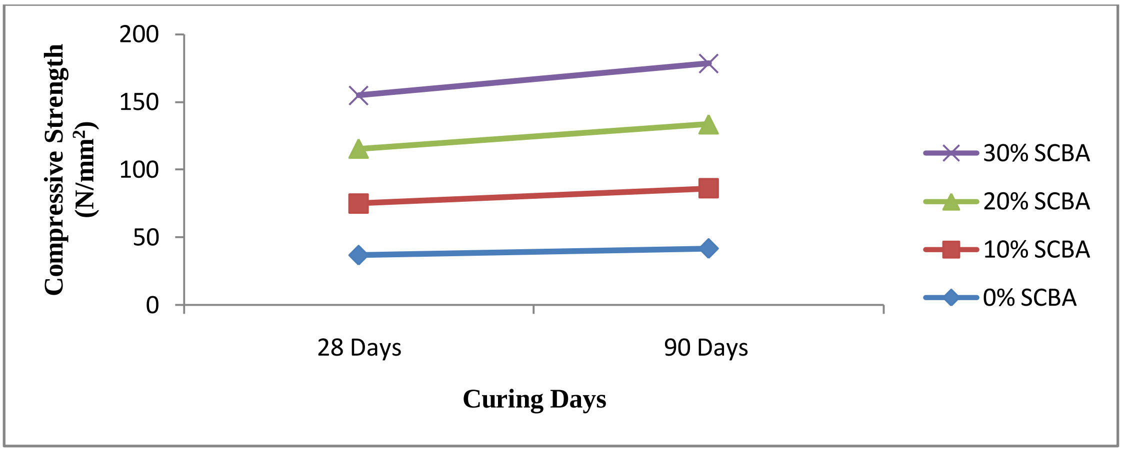

Figure 1: Compressive strength of SCBA concrete at different ages of curing

Srinivasan and Sathiya (2010)

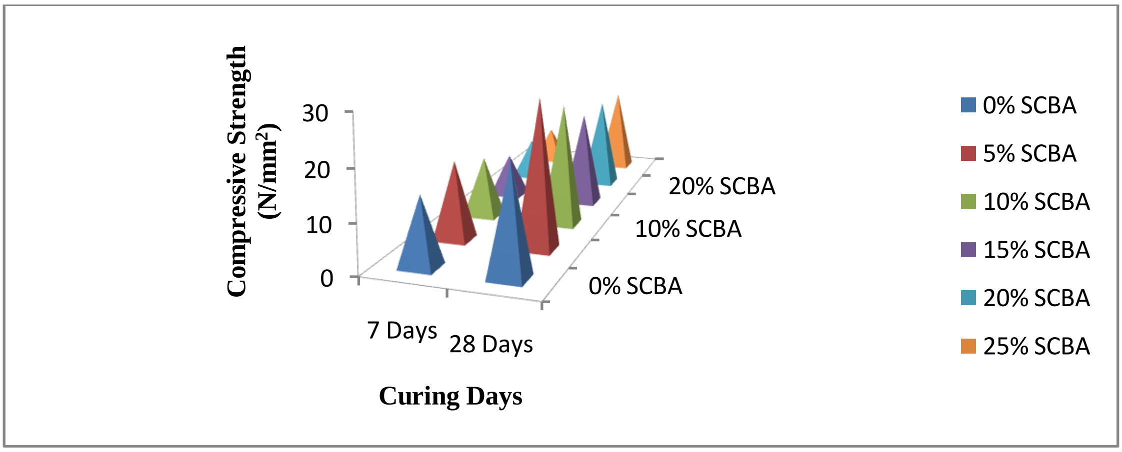

Figure2: Compressive strength of SCBA concrete at different ages of curing

3. Coal bottom ash

3.1 Properties of coal bottom ash

Coal Bottom Ash (CBA) is produced in furnaces of coal fired thermal plant. It is a non combustible material produced after burning of coals, mainly comprise of fused coarser ash particles. This unutilized ash has to be disposed off either dry or wet to an open area near the plant or mixing it with water and pumping into water bodies which causing pollution. To overcome this type of problem, it is necessary to utilize bottom ash. The CBA is well graded and majority of its grains sizes are similar to grains sizes of river sand. This grain size of CBA is within the limit given by Bureau of Indian Standard (BIS) specification. The physical properties of CBA are given in Table. 2.

Table 2: Physical properties of CBA

Physical properties	Malkit and sidddique(2013)
Colour	Grayish or Shiny Black
Particles shape and texture	Spherical, irregular and porous
Specific Gravity	1.39
Water Absorption	31.58%

3.2 Workability and strength characteristics of CBA concrete

Aggarwal *et al* (2007) observed the effect of coal bottom ash in concrete. They replaced the CBA with fine aggregates upto some proportions and studied workability, compressive strength, flexural and splitting tensile strength. The replacement was done by weight by preparing five mixes. First was without CBA and remaining four mixes contained CBA. The proportions of fine aggregate were replaced ranged from 20% to 50%. The samples were cured at 7, 28, 56, 90 days. The results revealed that the strength CBA concrete specimens were decreased. The results also showed that the workability of concrete decreased with the increase in CBA content due to the increase in water demand.

Andrade *et al* (2009) examined the CBA concrete. The concrete mixes were prepared by CBA addition. The fine aggregates were replaced up to 100% with CBA. The compressive strength of concrete was investigated at 3, 28 and 90 curing ages. The compressive strength is decreased with the contribution of coal bottom ash.

Kadam and Patil (2013) studied the effect of CBA as sand replacement on properties of concrete with different water cement ratio. In the study, natural sand was replaced with coal bottom ash by 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% by weight. The results showed that the compressive strength was increased up to 20% replacement and split tensile strength and flexural strength increased up to 30% replacement.

Malkit and Siddique (2013) studied the effect of coal bottom ash as partial replacement of sand. The examinations of density, compressive strength, flexural strength, split tensile strength and durability were reviewed in this paper from the published research work. The study pointed out that every examined aspects of concrete decrease when natural sand is replaced

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by coal bottom ash due to the porosity and higher water demand of coal bottom ash particles.

Malkit and Siddique (2014) investigated the strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate. Some of the mechanical properties of hardened concrete such as: compressive strength, modulus of elasticity and splitting tensile strength of concrete specimens were measured. The water cement ratio was kept constant at 0.45 for all the concrete mixes. At the early age, compressive strength reduced marginally on the inclusion of CBA in concrete. However, 28 days compressive strength of concrete was not found to be significantly affected by replacing river sand with coal bottom ash because pozzolanic activity of coal bottom ash is slow up to 14 days and starts after 28 days of curing age. Splitting tensile strength of concrete improved at all the curing ages on use of CBA as fine aggregate in partial or full replacement of river sand. Modulus of elasticity of concrete mix containing CBA as fine aggregate in partial or full replacement of river sand was lower than that of control concrete.

4. Hypo sludge

4.1 Properties of hypo sludge

Hypo sludge consists of low calcium and maximum calcium chloride and minimum amount of silica. It behaves like cementitious material because of silica and magnesium properties. Paper sludge consists of cellulose fibers, calcium carbonate, china clay and residual chemicals which bound up with water. The chemical properties of hypo sludge are given in Table 3.

Table 3: Chemical Properties of Hypo Sludge

Chemical compounds	Jayraj Vinodsinh Solanki & Jayeshkumar Pitroda 2013
Lime	37.97
Silica	11.92
Alumina	0.671
Magnesium	1.899
Calcium Sulphate	0.565

4.2 Workability and strength characteristics of SCBA concrete

Ahmadi and Khaja (2000) observed the effect of hypo sludge in the concrete. In their study, fine sand was replaced with waste sludge. Other than control mix, four concrete mixes were prepared by replacing 3, 5, 8 and 10% of fine sand. The results indicated that as the content of the waste increased the water to cement ratio for the mix was also increased, since the waste has a high degree of water absorption. An optimum of 5% content of the waste as a replacement to the fine sand in concrete mix can be used successfully as construction materials, such as in concrete masonry construction with a compressive strength of 8 MPa, splitting tensile strength of 1.3 MPa, water absorption of 11.9%, with a density of 20 kN/m^3.

Garcia et al (2007) established that an optimal condition for transforming paper de-inking sludge into a pozzolanic addition is

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achieved at 700°C maintained for 2 hours. Under these conditions, the organic matter disappears and the calcined sludge becomes active by transforming kaolinite into metakaolinite. The calcined product exhibits high pozzolanic activity. The analyses of mechanical, physical and chemical properties of a blended cement containing 90% (in mass) standard portland cement and 10% of the pozzolanic addition obtained from controlled calcination of paper de-inking sludge (for 2 hours at 700 degrees Celsius) was carried out. When the blended cement is compared with cement containing 100% standard portland cement, the following conclusions were mentioned: a significant gain in compressive strength from 7 days on, a sooner initial setting time, as well as a reduction in SO_3 percentage.

Pitroda *et al* (2013) studied the rate of absorption of water by capillary suction, "sorptivity" of unsaturated concrete which gives the measure of durability. There were total of five batches of concrete mixes, consists of every 10% increment of hypo sludge replacement from 0%, 10%, 20%, 30% and 40% by volume for M-25 and M-40 mix. The cylinders after casting were immersed in water for 90 days curing. The quantity of water absorbed in time period of 30 minutes was measured by weighing the specimen on a top pan balance weighting up to 0.1 mg. The water absorption and sorptivity of paper industry waste (hypo sludge) concrete shows lower water absorption and sorptivity at 10% replacement with paper industry waste (hypo sludge) for M25 and M40 grade concrete. There after the water absorption and sorptivity shows an increasing trend.

5. Conclusions

The published research literature shows that the strength development pattern of industrial waste concrete is much similar to that of conventional concrete. From the review of published research, it is concluded that:-

- Use of industrial waste in concrete will help in waste and pollution reduction.
- Its use in concrete construction will help in relieving the potential issue of dwindling natural resources.
- Its use will also help to reduce the material cost in construction.

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